The Soniscope — a Device for Field Testing of Concrete

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The determination of the quality of concrete in a structure or pavement has long been one of the difficult problems facing the engineer. He has generally relied upon visual inspection, such tests as rapping on the concrete with a hammer and listening to the emitted tone, and his judgment, to arrive at an estimate of the condition of the concrete. More and more during recent years, he has resorted to the removal of cores or beams from the structure for the determination of compression or flexural strength. The validity of such tests may be questioned in some cases because of the difficulty in ascertaining whether the concrete removed is truly representative of the concrete throughout the structure, because of the stress relief effected in the removal of the specimen and because the heat generated in drilling or cutting the specimen may influence its characteristics.

In 1946, the Hydro-Electric Power Commission of Ontario began experimental studies which resulted in the development of an instrument known as the Soniscope. Originating as a device for studying cracking in monolithic concrete, this instrument has proved to be a most valuable aid in studying concrete quality.

THE INSTRUMENT AND TECHNIQUE

Figure 1 shows the most recent model of the Soniscope and the two transducers used in conjunction with it. The main unit is 12 inches wide, 18 inches high and 22 inches deep and weighs 50 pounds. The transducers weigh approximately 5 pounds each and are connected to the Soniscope by coaxial cables which may be several hundred feet long.

The function of the Soniscope is to measure the velocity with which minute mechanical impulses travel through the concrete—or such other material as may be tested. This is accomplished largely through the use of electronic techniques. An electrical pulse generated in the main unit is converted into a very small mechanical impulse by the transmitting transducer (Right, Fig. 1). This impulse passes through a thin rubber diaphragm and into the concrete. After traveling through the concrete it is detected by the receiving transducer and converted back to electrical energy. This received signal is then returned to the main unit. Facilities are available for displaying the transmitted and received signals on the face of a cathode ray tube and for accurately measuring the transit time of the impulse in passing through the concrete. The distance between the transducers may be measured and the pulse velocity computed. The

Figure 1. Recent Model Soniscope.

development of the instrument has been reported by Leslie and Cheesman (2).

Although the Soniscope is composed of a number of complex electronic circuits, the operation of the instrument during the performance of a test is quite simple. Figure 2 shows the appearance of the traces on the screen of the cathode ray tube during the testing of a laboratory specimen. The small downward pulse near the left end of the upper trace represents the transmitted pulse. The train of oscillation starting near the right end of this trace is the received signal. The very sharp upward pulse on the lower trace is a timing strobe. Its position along the trace may be changed by rotation of a calibrated dial on the front panel of the Soniscope. This control is rotated to move the strobe toward the left until its steep left edge coincides with the left edge of the transmitted signal. The dial of the control then reads zero. The control is rotated to move the strobe to the right until its left edge is precisely aligned with the start of the first cycle of the received signal. The dial then indicates some number between 0 and 1000. This number may be referred to a calibration chart which will show the time, in microseconds, between

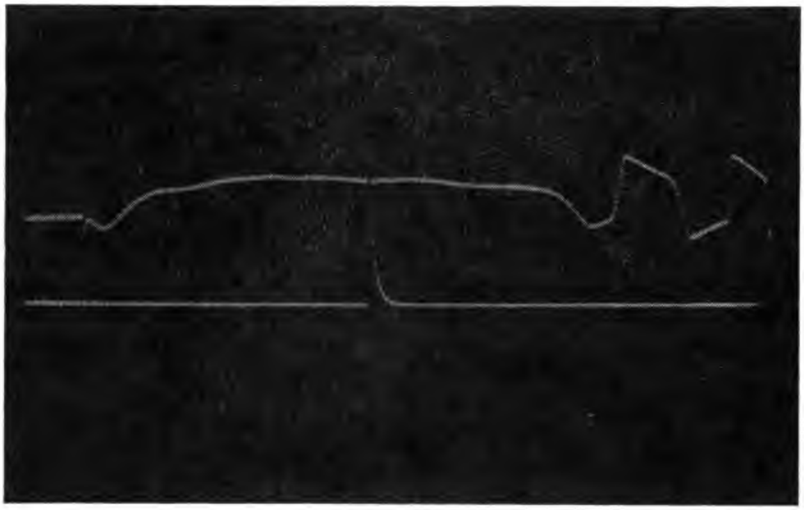

Figure 2. Appearance of Face of Cathode Ray Tube During Testing.

the two signals. The test may usually be completed in less than a minute, once the transducers are in place against the concrete.

INTERPRETATION OF TEST RESULTS

It may be stated, generally, that the higher the pulse velocity through a material the better is the quality of that material. Considerable experience with the technique has shown that for normal concretes, with densities of approximately 150 pounds per cubic foot, the following classifications may be established:

Velocity (feet per second)	Condition of Concrete
above 15,000	Excellent
12,000—15,000	Good
10,000—12,000	Questionable
below 10,000	Poor

These classifications, unfortunately, are not precise, exceptions having been noted in most categories. It should also be pointed out that, for concrete, pulse velocity will vary considerably with changes in aggregate, cement content or water-cement ratio. It is unwise to attempt to draw comparisons between different specimens or structures on the basis of pulse velocities, unless considerable data concerning the materials and practices of construction are available.

Aside from this very general classification of concrete as of good, poor or unknown quality, certain other information can be obtained from Soniscope tests. It is theoretically possible to use the velocity to compute the dynamic modulus of elasticity, the relationship being as follows:

$$E = 0.000216\, V^2 p \; \frac{(1+\mu)\,(1-2\mu),}{(1-\mu)}$$

with E = dynamic modulus of elasticity in pounds per square inch,
V = velocity in feet per second,
p = weight per cubic foot in pounds, and
μ = Poisson's Ratio.

As this equation is derived, the velocity used is the wave, or phase, velocity. On the basis of experimentation, it appears that in concrete this velocity is essentially equal to the pulse, or group, velocity and it is believed that the velocity measured with the Soniscope may be properly used. In testing field structures, the unit weight of the concrete and Poisson's Ratio are generally unknown and the assumption of these values leads to an inherent lack of certainty in the accuracy of the computed modulus.

The pulse velocity itself is a quantity which may usually be accurately measured, without influence of the size or shape of the specimen or structure. It is certain that any appreciable changes, with time, in the quality of the concrete in a given member will be reflected in appropriate changes in velocity. In the opinion of the writer it is preferable to deal only with velocities and the interpretation of changes therein rather than to endeavor to convert any individual velocity into an exact measure of the quality of the tested concrete.

USE IN LABORATORY TESTING

In any type of laboratory experimentation where it is desirable to study the progressive deterioration of concrete, the Soniscope is a suitable tool for acquiring the necessary data. Velocity tests, in this case, closely parallel the more conventional resonant frequency test which is now widely used. Cheesman (1) has compared the results of both tests on the same specimens undergoing 25 cycles of freezing and thawing and has shown them to be quite similar.

Recent tests in the concrete laboratory of the Joint Highway Research Project, Purdue University, have shown (3) that the Soniscope may be used to determine the setting time of concrete. Velocity tests are started on specimens shortly after they are cast and repeated at frequent intervals for eight hours or longer. The changes in velocity during this period are observed. It is found that the velocity increases at a rapid rate for several hours. The rate of change then decreases sharply within a short period of time. The time at which this decrease in rate of change in velocity occurs is taken as

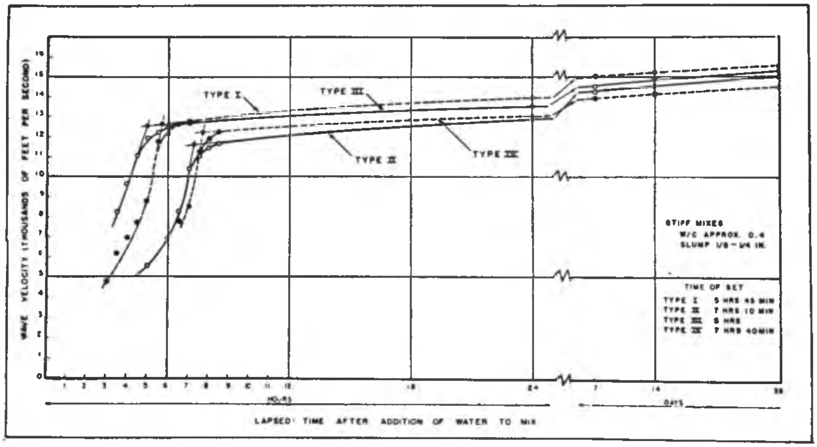

Figure 3. Comparison of Pulse Velocities Through Concrete Made from Type I, II, III and IV Cements.

the setting time of the concrete. Figure 3 shows the results of such tests on concrete made from Types I, II, III and IV cements.

USE IN FIELD TESTING

The Soniscope has been used widely in Canada and the United States for the testing of structures and pavements. In Canada the majority of the tests have been made on the hydraulic structures of the Ontario Hydro-Electric Power Commission. Leslie and Cheesman (2) have shown how such tests were used to carefully examine the slabs of an old Ambursen type dam. As a result of some 30,000 tests it was definitely shown that parts of several slabs were in need of extensive repair while others showed little distress.

Considerable work has also been done in Canada on the investigation of cracks. It has been shown that a very small discontinuity under test will have a notable effect upon the test results. In many cases the vibration will be completely cut off from the receiving transducer and no received signal will be observed. Under other conditions the vibration may be diffracted around the crack and eventually reach the receiver. When this happens, the vibration has traveled over a path longer than the apparent straight-line path and the computed

Figure 4. Testing Piles of Highway Bridge in North Carolina.
(Courtesy American Concrete Institute)

velocity will be low. It is sometimes possible to evaluate such an obviously low velocity in terms of crack depth.

In the United States, pulse velocity tests have been made on a variety of structures including dams, navigation locks, bridges and pavements. The writer (4) has reported on such tests made by the Portland Cement Association during 1948 and 1949. The majority of these tests were made with the expectation that they would be repeated periodically for the purpose of detecting early deterioration. Some of the structures have already been tested upon two or more occasions.

In the field, each structure offers its own individual problems with respect to testing. The approach selected will depend in part upon the information desired. Where a general measure of the quality of concrete in a structure is sought, it is desirable to send the test vibrations through long paths of concrete. This will tend to produce more generally representative, or average, test data. Thus, where this type of information was desired for highway bridges in Georgia, most of the tests were made through the length of the pier caps, distances varying from 25 to 50 feet. In some cases such convenient members are not available for test. Also, where more specific data are required, shorter path lengths may be desirable. A few cases will be cited.

A bridge in North Carolina is supported on more than one thousand 16 and 18 inch octagonal concrete piles. Some of these piles have suffered severe deterioration near the water level. As a possible reclamation measure it was suggested that the distressed concrete be chipped away and concrete collars cast around the damaged sections. It then became necessary to determine the extent of the distress. Caissons which had been placed around several of the piles permitted inspection of these from river bottom to pier cap. Velocity tests were

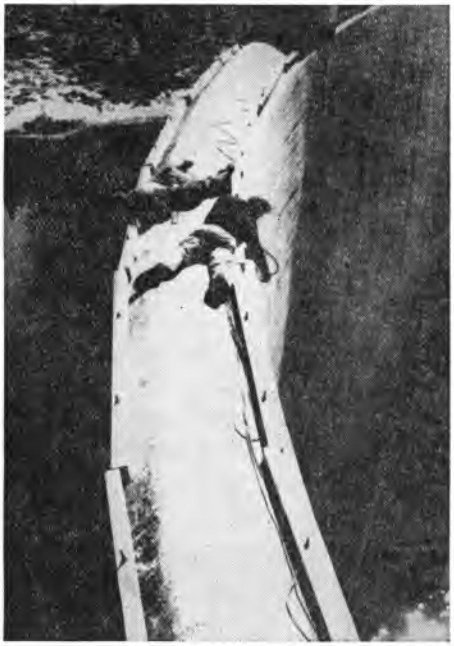

Figure 5. Testing Arch Dam in California.

made at intervals along the entire length of these piles and numerous others were tested from water level to cap. Figure 4 shows how the tests were made. As a result of these tests it was determined that some deterioration had occurred from water level to three or four feet above this level, although the visual evidence of distress was much more limited in extent.

A small arch dam located at high altitude in California was tested in 1949. Information was desired concerning the general quality of the concrete. Visual inspection showed no evidence of distress. The size and shape of the dam and its location in the canyon were such that considerable rigging would have been required to test concrete centrally located in the structure. It was decided that the concrete lying along the crest of the arch was likely to be in as poor condition as any in the dam. Accordingly, a number of tests were made along the crest. Figure 5 shows the transducers being held in place for one of these tests. The Soniscope was about 100 feet from the end of the arch. Velocities were found to be consistently high and it was concluded that the quality of the concrete in the structure was good.

Tests have been made on several highway pavements on both the east and west coasts. Figure 6 shows the approach usually selected for these tests. A hole is scooped in the shoulder of the road and the transmitting transducer is pressed against the edge of the slab. The

Figure 6. Testing Pavement Slab in New York.
(Courtesy American Concrete Institute)

receiving transducer is held against the surface of the slab several feet from the edge and the velocity of the pulse traveling between the two points is measured. If the receiver is moved from place to place while the transmitter is held in its original position and the several velocities measured are found to be essentially the same, it may be concluded that the tests are reliable. On numerous occasions it has been noted that when the receiver is held close to the edge of the pavement, within about three feet, the velocity appears to be lower than when it is held near the center of the slab. This would indicate that minute cracks were interfering with the transmitted pulse near the edge of the slab.

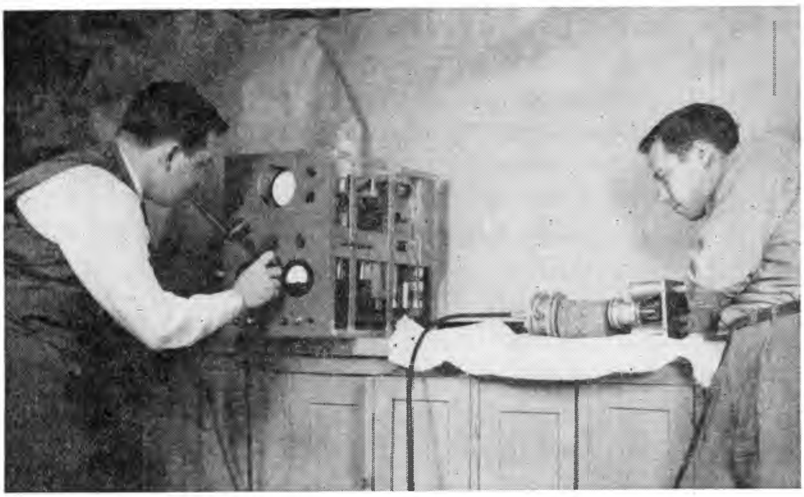

Figure 7. Testing Soil-Cement Specimen.

TESTING OF OTHER MATERIALS

Although the purpose of this paper is to report on the most recent developments in the field of concrete testing, it might be in order to remark briefly on other applications to which the Soniscope has been and is being put.

During recent months, tests have been made on compacted soil specimens, with and without stabilizing admixtures. Figure 7 shows a test being performed on a soil-cement specimen. Results indicate that data acquired by such tests on specimens undergoing freezing and thawing may be more reliable than those gathered through the conventional brushing test. Current studies are being made on the influence of materials, density and moisture content upon velocity. The limited results to date are most encouraging.

A few tests have been made on specimens of bituminous mixtures. These were too limited in scope to be of value, except to indicate the possibility of adapting the Soniscope to tests of these materials.

SUMMARY

The foregoing has shown some of the uses to which the Soniscope may be put. The following remarks are offered in summarization of the present status of the instrument:

1. The Soniscope has been used to measure the velocity of pulse propagation through concrete sections varying from 2 inches to more than 50 feet.

2. The velocity so measured may be used to identify concrete of either very good or very poor quality. If information concerning mix design and materials of construction is available, concrete of intermediate quality may sometimes be classified.

3. These velocities may be used to determine the variability of the quality of concrete in any given structure.

4. Velocity tests may also be used to detect and evaluate progressive deterioration in either laboratory specimens or field structures. The method permits a direct comparison of concrete performance in the laboratory and under field conditions.

5. The Soniscope may be used to determine the setting time of concrete, at least in the case of laboratory specimens. It is probable that this technique may be extended to include concrete in place.

6. Under some circumstances the Soniscope may be used to investigate cracks in structures and to determine whether or not construction joints are tight.

7. Although the instrument itself is complex, the test is easily and quickly performed. It is non-destructive, quantitative and economical and is apparently the only test meeting these requirements which is presently applicable to concrete in place.

It is believed that in the Soniscope a powerful new tool is available to the engineer who would study concrete quality. It is probable that its full potentiality is not yet appreciated. It is certain that further reports of its usefulness will be forthcoming in the near future.

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